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Economic viability of biogas and green self-employment opportunities

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ABSTRACT

To analyze economic viability of the biogas plants in Bangladesh six case studies are carried out in some selected upazilas of greater Sylhet district in Bangladesh where NGOs like Grameen Shakti (GS) and Rural Services Foundation (RSF) are delivering and servicing biogas plants. Economic viability of the biogas plants are measured by comparing prior expenditure (before implementing biogas plant) for firewood, kerosene, and other conventional sources. Economic viability refers to an estimator that not only seeks to maximize the effectiveness of financial viability but also considers environmental externalities. Economic viability for six different cases of biogas plants provides information about relative performance of the product in six different situations. A sensitivity analysis is performed using artificial neural network (ANN) model. Although economic viability of biogas is sensitive to kerosene price, firewood availability, this study reveals that biogas is economically more attractive when women could render their saved cooking time for other income generating green jobs. Biogas plant results a number of income generating new green employments for the rural community in Bangladesh.

Contents

1. Introduction

Worldwide, 2.7 billion people or over 40% of the global population rely on using traditional biomass (wood, dung and agricultural residues) and coal to meet their energy needs for cooking, among

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them 82% of the population live in the rural areas in developing countries [1,2]. In Bangladesh, over 90% of the population is using biomass to meet their energy requirements and it is estimated that 39 million tons of biomass matters are burnt away every year [3]. As usual, this situation is even worse in rural areas where around 75% of the population resides, 78% of them have no electricity and natural gas connection in Bangladesh [4]. Overall, only 7% of urban people of eastern parts of the country use natural gas for their cooking [5], among them 3% use natural gas delivered by pipeline [6]. The shares of different types of fuel consumption are as follows in Bangladesh: natural gas 12.2%, oil 10.1%, coal 1.8%, electricity 2.8 and biomass fuels 73.1% [7]. The biomass energy is supplied mainly from three sources: forest, agricultural crop, livestock and poultry. A major share of biomass energy is supplied from designated forest areas, which are the real forests, homestead trees and road side trees and other social forests. As a result of this, a large amount of deforestation is going to happen every year to meet energy demand. According to a statistics during the last 30 years, 35–45% of the total forest area has been decreased in Bangladesh [4]. As a result supply of fuel wood is also decreasing and it is becoming scarce and fuel price is increasing day by day.

As an alternative fuel, biogas could become a potential source of green energy for cooking as well as for conserving natural resources. Easy availability of cattle dung is an important source of biogas in Bangladesh. There are about 22 million cattle in Bangladesh, which produce about 0.22 million ton of wet dung daily [4]. However, the microeconomic feasibility study is needed to understand the nexus between private financial feasibility and environmental concern, which is calculated in this paper by introducing environmental and social cost in private financial calculation. As discussed, economic analysis also considers home environment which relates to health outcome, housewives are cooking meals using traditional biomass fuels that cause serious indoor air pollution for fume-contaminated air. According to a report of the World Bank, concentration of respirable airborne particles (PM10) for using traditional biomass fuels in Bangladesh is found to be 300 μg/m^3 or greater [8], the standard for annual recommended average for PM10 in Bangladesh is 50 μg/m^3 [9]

As a result, a great number of people suffer from acute diseases and 46,000 people dies of them, of which children′s share is almost 70% in Bangladesh [10]. Therefore, use of biogas could reduce extreme dependency on conventional fuel sources, cooking with biogas does not generate harmful gases emissions in indoor air [11] and thus ensure health quality of its household. One biogas plant in Nepal could save about 250 kg of firewood per month. Thus saving of firewood from each household per year is about 3 t. Similarly the saving of cow dung being directly burnt is 48 kg per month. Every biogas system in Nepal can avoid nearly 4.5 t of carbon emissions per year by reducing the use of firewood in the kitchen [12]. Generally renewable energy technologies reduce carbon emission and generate employment and income. This includes jobs that help to protect ecosystems and biodiversity; increase energy efficiency, de-carbonize the economy; and minimize waste and pollution. Therefore green jobs are associated with sustainable development via inexhaustible energy sources [13]. Green job can be created by a biogas plant in two different ways: self-employed in domestic biogas plant or generating other sort of employment using biogas technology, paid-up employment in biogas plants. This research focused green employment in a way to be self employed using biogas plants directly or indirectly.

2. Biogas plant

In Bangladesh, three types of biogas plants (floating gas-holder, fixed dome, bag system) were being tried. Of them, fixed dome digester shown in Fig. 1 is the most popular and widely used in Bangladesh.

The fixed dome plant shown in Fig. 1 employs a mixing tank with inlet pipe and sand trap (1), a digester (2), compensation and removal tank (3), gasholder (4), gaspipe (5), entry hatch, with gastight seal (6), accumulation of thick sludge (7), outlet pipe (8), reference level (9), supernatant scum, broken up by varying level (10).

Since the dome is fixed, this gas plant is known as fixed dome type. The digester is normally constructed using bricks and mortar and ends with a solid fixed dome in the shape of an igloo. This type of digesters works on principle of constant volume, changing pressure. When gas production starts, slurry is displaced into the compensation tank. Gas pressure increases with volume of gas stored and height difference between the slurry level in the digester and the slurry level in the compensation tank. When the rate of gas production is higher than that of gas consumption, pressure inside the digester rises and expels some digester contents into the outlet compartment. The gas is captured in the gasholder and the slurry is displaced in the compensating tank. The more gas is produced, the higher the level at the slurry outlet will be [14]. The fixed dome digester is relatively inexpensive and a lifespan could be expected up to 20 years [15]. The plant is constructed underground, protecting it from physical damage and saving space. The construction of fixed dome plants is labor-intensive, thus creating local employment.

3. Service providers in Bangladesh

Infrastructure Development Company Limited (IDCOL), established on 1997 is playing a major role in bridging the financing gap for developing medium and large-scale infrastructure and renewable energy projects in Bangladesh. The company now stands as the market leader in private sector energy and infrastructure financing in Bangladesh. Since its inception, IDCOL′s stakeholders include the government, private sector, NGOs, to provide renewable energy in the village level in Bangladesh. Among the Non-Governmental organization, Grameen Shakti and Rural Service Foundation are two most active and operating in large scale in Sylhet division.

Grameen Shakti (GS) has one of the most successful market based bio gas programs with a social objective for popularizing the program including other renewable energy technologies to millions of rural villagers. GS′s biogas program is the first market based program in Bangladesh and have become popular among the rural people and show an accelerating trend in Fig. 2 [16].

GS has developed an integrated and sustainable model for expanding biogas program. GS plays the role of a facilitator, not of a provider. GS provide soft micro loans [16], which makes biogas plants affordable to the villagers. They also offer service including monthly visits by GS engineers for two to three years. They also

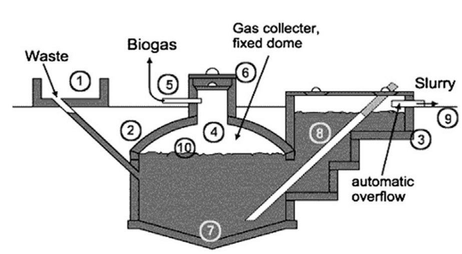

Fig. 1. Typical elements of a fixed dome plant for biogas systems.
Source: http://energypedia.info/images/0/03/Nicarao_biogas.gif [accessed on January 18, 2012].

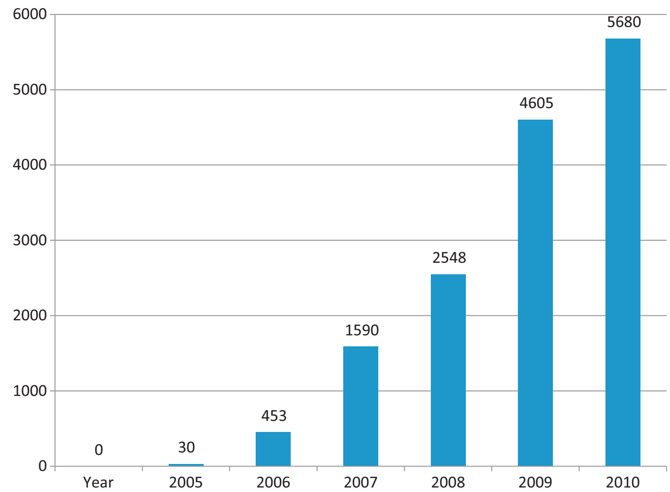

Fig. 2. Year wise biogas plant construction by GS.

offer training of GS staff, local masons and users. In Sylhet division, Grameen Shakti is operating its biogas program through two branch offices in Gwalabazar and Bishwanath respectively. Gwalabazar office has built 92 plants and Bishwanath office has build 101 plants.

Rural Services Foundation is a social development initiative of Rahimafrooz which has installed 779 biogas plants till June 2011 [17]. In Sylhet division, Rural Services Foundation has eight regional offices but operating its biogas program through its branch office in Tajpur, Osmaninogor. This office has built 35 plants in the Osmaninogor region.

4. Study area and methodology

Study area consists of three upazilas in greater Sylhet: Bishwanath, Balagonj and Jogonnathpur. NGOs like Grameen Shakti (GS), a sister organization of Grameen Bank and Rural Services Foundation (RSF), a sister organization on Rohimafrooz Company Ltd. provide biogas plants in these Upazilas. Grameen Shakti has two area offices to provide their biogas service, one in Bishwanath Upazila and other in Gualabazar at Balagonj Upazila. Rural Services Foundation (RSF) has one area office in Tajpur village at Balagonj Upazila. More than two hundred biogas plants have been established by these two organizations within the three Upazilas.

4.1. Economic analysis:

Although both economic and financial analyses aim at appraising profitability of an investment project, the concept of benefit in economic analysis differs significantly from the financial analysis. Domestic biogas programs are frequently justified on the basis of financial cost-benefit analysis in terms of providing a superior cooking fuel (displaces dirtier and less efficient cooking fuels viz., firewood, kerosene etc.). Individual households judge profitability of biogas plants primarily from monetary surplus gained from utilizing biogas and bio-fertilizer in relation to the cost of the plants. The financial analysis is concerned with owner's private cost-benefit of the project without considering environmental or social externalities; however an economic analysis considers externalities due to project execution. Therefore, social cost-benefit analysis relies mainly on microeconomic theory [18]. In this respect, economic analysis has a much broader scope than the financial analysis for policy consideration. Economic cost-benefit analysis is the most efficient and widely used tools for measuring whether any investment would be beneficial or not along with their environmental and social concern.

The following effects, to be documented and provided with a monetary value, should be listed as benefits: expenditure saved by the substitution of other energy sources with biogas, income from the sale of biogas (if applicable), replacing cost of using chemical fertilizer by slurry, income from the sale of slurry (if applicable), time saved for collecting and preparing previously used fuel materials (if applicable) [11], time saved for cooking after utilizing biogas (if this time can be used to generate income), improved indoor air quality and consequent reductions in medical expenditure for respiratory infections.

Along with the above benefits this paper identifies a major research gap that biomass has not been closely examined in terms of a substitute for fossil fuels compared to carbon sequestration and overall environmental benefit [19]. The main environmental benefits of a biogas plant are: savings attributable to less (or no) consumption of conventional energy sources (e.g. firewood, kerosene, etc.) and thus avoided CO_2 release from burning firewood for cooking. A study shows that domestic cook stoves as a significant source of greenhouse gas emissions [20], the emissions generated by using firewood and improved cook stoves are around eight times higher than biogas [21]. However, as Johnson et al. [22] mentioned, measurement and verification of emissions in households spread over wide distances are much more complex than, for example, calculating industrial emissions [23]. Considering this complex issues this study considers environmental benefit in terms of Taka by using the following conversion factors for different traditional fuels: 1 kg firewood emits 1.83 kg of CO_2 [24], 1 l kerosene emits 3.15 kg CO_2 [25], 1 l LPG emits 1.492 kg CO_2 [26], 1 kg dry dung emits 2.5 kg CO_2 [27], 1 t CO_2 is 20 USD [28]. Benefit from saving of traditional fuels is calculated by using the above conversion factors.

As far as costs are concerned there are the following major categories: manufacturing or acquisition costs (production costs) including capital costs. The production costs include all expenses and lost income which are necessary for the erection of the plant e.g. the land, excavation work, cost of material for building the digester, gasholder and displacement pit (cement, bricks, blocks), gas stove, the piping system, the dung storage system etc. Operation and maintenance costs mean running costs including cost of raw dung or foregone revenue from sale of raw dung. While the average plant has a service life of 10–20 years, other costs may arise on a recurrent basis. Otherwise, the operating costs consist mainly of maintenance and repair work needed for the gas piping and gas appliances. GS provide free after sales service including monthly visits by plant maintenance experts for two to three years. There is also an option for signing annual maintenance agreement for a small fee during post warranty period.

When conducting the economics of cost-benefit analysis (CBA) for an investment project, all costs and benefits exclusively attributable to the project are considered and the "with project" situation is compared to the "without project" situation; here "without project" situation is the next best alternative to the project. NPV (net present value), IRR (internal rate of return) and simple payback period are used for determining economic feasibility of biogas plant [28]. Eq. (1) is represented to calculate NPV:

$$\mathrm{NPV}_{A1:A2} = \sum_{t=0}^{N} (B_t - C_t)/(1+d)^t \tag{1}$$

where $\mathrm{NPV}_{A1:A2}$ is NB, i.e., present value benefits (savings) net of present value costs for alternative $A1$ (with project situation) as compared with alternative $A2$ (without project situation), B_t is benefits in year t, which may be defined to include energy savings, C_t is costs in year t associated with alternative $A1$ as compared

with a mutually exclusive alternative $A2$, and d is the discount rate [28].

The internal rate of return (IRR) is the discount rate that makes the present value of future benefits equal to the present value of any costs, thereby causing NPV to equal zero. Payback period is the period of time over which the accumulated cash flows will equal the initial outlay, i.e. payback period is the amount of time that takes for a project to recover its initial investment. A short payback period may be desirable to ensure that the capital expenditure is quickly recovered and repatriated so that at least the initial investment will have been recovered. An investment is profitable when its NPV is zero, the bigger NPV the better.

4.2. Sensitivity analysis in multilayer perceptron (MLP) model

Sensitivity analysis is required to identify those input variables that are important in terms of contributing to predict the output variation and in quantifying how changes in the values of input parameters alter value of the output variable. Sensitivity of variables is often a non-linear, complex and unsteady process, so it is difficult to derive a linear formula to represent influence of all variables in the process. Furthermore, simplifying the nature of analysis using a linear model would lead to unreliable results in practical applications of this research. Therefore, the neural network is used as an alternative way of sensitivity analysis because it considers linearity and non-linearity; it is faster, accurate, viable and efficient alternative against the traditional techniques of sensitivity analysis [29]. Several authors have used Artificial Neural Network (ANN) to perform sensitivity analyses [28–37].

This study follows Multilayer Perceptron (MLP) model with back-propagation of error correction algorithm to estimate sensitivity of the variables used in economic analysis. The Multilayer Perceptron (MLP) with back-propagation remains the dominant neural network architecture [37]; sensitivity measure by the MLP is defined as the mathematical expectation of output deviation due to expected input deviation with respect to overall input patterns in a continuous interval.

There are some aspects that must be highlighted to support the option of investigating applicability of back-propagation algorithm using MLP in determining variable sensitivity [29,30]: The MLP poses no theoretical constraints on data, it supports more than one output in input–output mapping, it is capable of linear and non-linear mapping with only a very limited quantity of observed data points and it possess more tolerant of noise in contrast to traditional measurement tools.

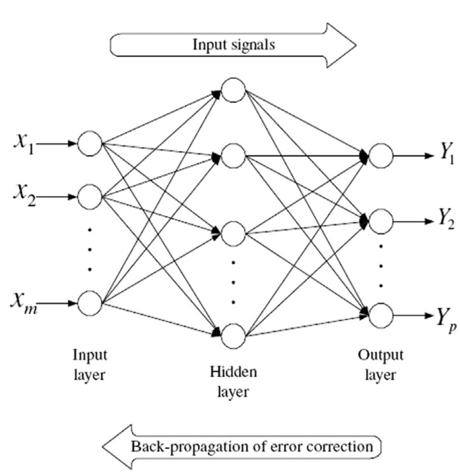

Fig. 3. Typical architecture of an MLP network [29].

Fig. 3 shows a typical architecture of an MLP model consisting of three layers of interconnected neurons. This architecture is represented as $m \times n \times p$, where, m is number of neurons in the input layer, n is number of neurons in the hidden layer, and p is the number of neurons in the output layer. Each neuron in every layer is fully connected to all neurons in the higher layer, and each connection has a weight associated with it. The sigmoid logistic function as an activation function is used to calculate the output of the neurons in the hidden and output layers. The back-propagation algorithm is used as a learning mechanism to correct connection weights iteratively and to minimize system error produced by each forward processing of the input variation. Training was carried out until the average sum of the squared errors over all training patterns was globally minimized. On completion of training phase, the testing phase was conducted using those input patterns that were not included in the training set; this was performed to assess the generalization ability of the trained neural network. We defined a "relative strength of effects (RSE)" to evaluate the influence of each components of capital inflow (green job, medication, LPG, slurry, kerosene, firewood) and outflow (construction cost, instrumental price and input price) on the net cash flow.

Considering a well trained MLP model with $m \times n \times 1$ network architecture (i.e. m input nodes, n hidden nodes, and 1 output node), the procedure for calculating the relative importance of input variables is as follows [29]:

Step 1. Arrange a row vector, M $(1 \times n)$, for the interconnection weights between the hidden layer nodes (n nodes) and the output layer nodes.
Step 2. Arrange an $m \times n$ matrix, W, for the interconnection weights between the input layer nodes (m) and the hidden layer nodes (n).
Step 3. Calculate the row vector, $R = MW^T$, in which $R = [r_1\ r_2\ r_3 \cdots r_m]$.
Step 4. Calculate the relative importance, RI_i (in percentile), of the input node i, as given by Eq. (2).

$$RI_i = \frac{r_i}{\sum_{i=1}^{m} |r_i|} \times 100(\%), \quad i = 1 \text{ to } m \tag{2}$$

The relative importance, RI, provides an index for evaluating the contribution or influence of each input variable to the output variable. This enables us to determine the most sensitive factors that significantly affect economic viability of the biogas plant. An input with higher RSE has a stronger sensitivity on the final output.

5. Selected case studies

Six cases were analyzed here to find out economic feasibility of biogas plants considering previous expenditure for firewood, kerosene, etc. Three discount rates (such as 6%, 9% and 12%) are used as interest rate of savings paid by commercial banks and lending rate of commercial banks in Bangladesh at different time points (5, 10, 15, 20 years). As discussed, the respondents used different types of conventional energy sources before installing the biogas plants. We describe all the cases in Appendix A

5.1. Case 1: Plant size 2.4 m^3, saves 450 kg firewood and 1 l kerosene per month.

Before installation of biogas plant, wife and eldest daughter of Mr. Ali cooked food on open fire for 8 members of their household and they spend 7–8 h per day for preparing meals. They required 100 kg firewood and 1 l of kerosene per month for cooking. As a

result of burning firewood and kerosene their indoor air quality was very bad and they spend around Taka 1000 ($1 = Tk. 80) per year as medication cost of airborne diseases. After installing the biogas plant this household reduced 50% of firewood consumption per day. Cooking time for women was reduced by 4 h per day, however, they do not use this saved time for income generating activities, and they treat this extra time as leisure. The biogas digester produces 25 kg (Tk. 9/kg) slurry each day and this slurry is applied to crop field and as a result the household saves chemical fertilizer of Tk. 4500 per year. When Mr. Ali initiated the installation of biogas digester in early 2008, he possessed seven cows, but at the end of 2008, 4 of his cows were died for unknown diseases. After this incidence only three cows could provide 35 kg (Tk. 5/kg) of dung per day, which could not meet minimum basic requirement of the bio-digester. Basic information for this case is presented in Appendix A.

5.2. Case 2: Plants size 2.4 m^3 and no use of slurry.

Before installation of biogas plant, Mr. Kala Mia′s daughter in law spent 8 h every day to prepare food for the household. She used 20 kg (Tk. 5/kg) firewood everyday and 3 l of kerosene per month for cooking; their kitchen environment was polluted with dust and smoke. As a result she has to pay Tk. 1100 per year as medication cost for airborne diseases. After installing biogas woman engaged in cooking get relief from eye and lung problems that are associated with the smoky kitchen environment.

Encouraged by his neighbor, Mr. Kala Mia installed a 2.4 m^3 size plant in November 2010. At that time he own four cows but in January 2011 one of his cows died. As a result the dung production reduced to 25 kg. Installation of this plant results only 2 kg reduction of fuel wood use per day and 2 l reduction of kerosene usage per month. Women workload reduced by 1.5 h per day which they spend as leisure time. The plant produces 20 kg slurry, however, benefits derived from fermented slurry has no immediate monetary value since the household head has no idea about its importance that slurry could replaces commercial fertilizer. Thus there is no reduction of chemical fertilizer use and thus no savings of cost for using fertilizer in the paddy field. Basic information for this household is summarized in Appendix A.

5.3. Case 3: Plant size 2. 4 m^3, raw materials collected from seven cows, five cows are newly bought.

Before installation of biogas plant, Mr. Uddin′s mother (65 years old) spent 5 h to prepare food using firewood and LPG. It was very difficult for her to cook in the smoky and dusty environment and she had to spend Tk. 1200 as medication cost. He then established a biogas plant of 2.4 m^3 size and purchased 5 cows worth Tk. 140,000 and appointed a person to take care of cows and operate the plant with Tk. 30,000 as salary per year.

After installation of the plant, their firewood use reduces to 132 kg per year and kerosene use also reduces 24 l per month. Cooking time is saved by 3 h and this time is devoted as leisure time. They could save their medication cost and receive intangible environmental benefit per year. The plant produces 80 kg slurry, financial saving from replacing chemical fertilizers is about Tk. 20,000 per year. Basic information for this household is summarized in Appendix A.

5.4. Case 4: Plant size 2.4 m^3, self green employment created for female family member.

Plant owner Mr. Abdul Kalam is the head of the eight members family. His wife cooked food for the entire family using 600 kg of firewood and half kg of kerosene per month; she required 9 h for cooking before plant installation. Due to poor indoor air quality, the family had to pay Tk. 800 per month. Learning from a biogas seminar, they installed a plant in September 2009, where they could use 90 kg of dung every day from their domestic animals. Mr. Abdul Kalam also appointed a person for operating the plant. The cash inflow and outflow variables are summarized in Appendix A.

After installation of plant, their use of firewood reduces 14.5 kg (73%) and kerosene use remains unchanged. Now their medication cost reduced by Tk. 300 per year and women can save 2 h from their cooking time. A female member of the family uses this saved time for tailoring from which she earns Tk. 1200 per month. Out of 50 kg slurry produces every day, they uses only 30 kg to their crop field and rest are kept useless. Their savings from chemical fertilizer is Tk. 5700 per year. Thus biogas investment increases their family earning, improve indoor air quality, increase crop productivities etc.

5.5. Case 5: Plant size 2.0 m^3, saves firewood, kerosene, dried dung and chemical fertilizers.

Mr. Torab Ali is the head of a five member′s household and a firmer. Before installing biogas plant his family used 5000 kg firewood, 50 l of kerosene and 2000 piece dried dung stick every year for cooking their meal and his wife spent 6 h a day for preparing meal. This results indoor air pollution and cost them Tk. 1100 per year for treatment. Due to financial constraint, Mr. Torab Ali installed a small size plant 2.0 m^3 even though he could run a 3.2 m^3 plants by 80 kg dung he could get from his 8 cows. So this household could only replace 55% (360 kg.) of firewood and 25% of kerosene usage, thus they produced intangible environmental benefit of Tk. 12,665 per year. They could also save their medical cost for indoor air pollution of Tk. 1100 per year. Mr. Ali′s wife could save 3 h cooking time every day and she utilize this time for income generating activity such as poultry farming and managing dung for the biogas plant. She earns Tk. 1000 out of poultry firming per month. The plant also produces 60 kg slurry which is used in crop field. As a result they can also save chemical fertilizer worth Tk. 4100 each year.

5.6. Case 6: Plant size 2.4 m^3, saves only 120 kg firewood and 2.5 l kerosene per month.

Before installing biogas plant, Mr. Haque (a farmer and head of the 6 members household) used 270 kg firewood and 3 l of kerosene per month for cooking food, his wife required 7 h each day for preparing food in an open fire. As a result, indoor air condition was polluted and cost her Tk. 1000 per year to combat respiratory problem. The biomas and fossil fuel based cooking system is now replaced by a 2.4 m^3 plant, provided by the GS. The replacement of firewood and kerosene with biogas for cooking saves 33% of firewood (99 kg) and 17% of kerosene (0.5 l) usages per month, preventing a release of CO_2 (about Tk. 8000 per year) every year. The cooking time for Mr. Haque′s wife saved for about 5 h a day and she used this time for income generating activities (poultry firm) and she earns Tk. 680.

After installing the biogas plant medication cost reduces by Tk. 500 per year and the plant produces 40 kg slurry each day, which also save Tk. 1600 per year from use of reduced chemical fertilizer. During installation, he had 6 cows and the numbers of cows were sufficient to produce dung as per requirement of the biogas plant. At the beginning of 2010 two of his cows were died; since then, he has been paying for purchasing/collecting cow dung. He also appointed a person (Tk. 35,000 yearly salary) for operating the plant and taking care of their cattle.

6. Results and discussion

This section constitutes results and discussion of a micro-economic analysis which judges profitability of a biogas unit from the perspective of user and society considering environmental valuation in concern. Findings of the economic analysis based on payback period, NPV and IRR are summarized in Table 1. The biogas plant can be regarded as profitable, if its net present value is found to be equal to or greater than zero for the minimum acceptable interest rate. NPV is negative for two (case-1 and case-2) out of six cases at 6%, 9% and 12% discount rate for all consecutive periods until 20 years, while considering case-3 NPV is only positive after 5 years of gas production by the bio-digester. In all other cases (case-4, case-5 and case-6) NPV is positive for all the 5 years interval time until its total lifespan of 20 years.

Some biogas plants are not economically feasible even after considering environmental benefit (carbon finance) for savings conventional sources of energy like firewood and kerosene (case-1 and case-2). However, sometimes it is argued that many environmentally worthwhile projects are rejected by financial analysis because NPV is negative and/or IRR could not meet the minimum requirement [28]. Since biogas is competing with heavily subsidized fossil fuel (i.e. kerosene), and solid biomass (primarily fuel wood and to some extent also crop and animal residues) which can be collected albeit free from conserved forest of the locality, implies lower and sometimes no forgone costs, and hence lower financial benefits for implementing biogas plant. Therefore, NPV is negative for some cases even after considering “environmental value” in the analysis (Table 1, case-1, case-2 and case-3). This means that financial investment of biogas plants in case-1 and case-2 fail to break even over 20 years for artificially lower kerosene price and almost free fuel wood. However, at the same time, given existing kerosene subsidy and cheap fire wood collection, results in Table 1 show that case-4, case-5 and case-6 have positive NPV, these cases have a higher IRR and small payback period. Then a question might arise: why does a particular case (for example, case-4, case-5 and case-6) differ from the other case (for example, case-1, case-2 and case-3) in terms of NPV?

Sensitivity analysis (Section 4.2) answers the question. The MLP model discussed in Section 4.2 has the capacity to identify key variables affecting viability of the biogas plans for each case and the results are presented using an index “relative importance” for evaluating sensitivity of each input variable to the output variable. Fig. 4 illustrates the results of a sensitivity analysis using MLP model to study relative importance associated with some of the input variables which affect economic viability of the biogas plants. The importance of an independent variable means how much the network′s model-predicted value changes for different values of the independent variable expressed as percentages [28].

Sensitivity analysis considers all possible components that vary because of the nature of traditional cooking system and biogas usage pattern (recurring and capital costs). Therefore, this analysis has been carried out considering different key parameters, e.g.

Table 1
Summary results of economic analysis (units are measured in Tk.).

Cases	Indicators	Five year	Ten year	Fifteen year	Twenty year
Case 1	Environmental benefit	74,398.5	148,797	223,195.5	297,594
	Green self employed earnings	0	0	0	0
	NPV (6%)	−51,963.11	−54,545.18	−56,474.66	−57,916.48
	NPV (9%)	−52,179.41	−54,253.13	−55,600.91	−56,476.87
	NPV (12%)	−52,388.30	−54,066.18	−55,018.25	−55,558.48
Case 2	Environmental benefit	10,449	20,898	31,347	41,796
	Green self employed earnings	0	0	0	0
	NPV (6%)	−221,544.31	−348,398.19	−443,190.78	−514,025.33
	NPV (9%)	−208,063.52	−309,942.68	−376,157.15	−419,192.01
	NPV (12%)	−196,136.70	−278,568.62	−325,342.70	−351,883.57
Case 3	Environmental benefit	49,387.5	98,775	148,162	197,550
	Green self employed earnings	0	0	0	0
	NPV (6%)	−7,397.85	118,683.84	216,598.46	289,765.96
	NPV (9%)	−20,588.80	79,896.19	148,291.45	192,743.68
	NPV (12%)	−32,217.44	48,366.26	96,680.87	124,095.87
	Simple payback periods (year)		3.86	2.02	1.36
	IRR (%)		18	21	22
Case 4	Environmental benefit	72,468	144,936	217,404	289,872
	Green self employed earnings	72,000	144,000	216,000	288,000
	NPV (6%)	222,522.07	427,166.89	580,089.41	694,362.01
	NPV (9%)	201,789.74	366,144.54	472,963.89	542,389.13
	NPV (12%)	183,504.58	316,486.45	391,943.93	434,760.53
	Simple payback periods (year)	0.81	0.37	0.24	0.18
	IRR (%)	138%	140%	140%	140%
Case 5	Environmental benefit	63,325	126,650	189,975	253,300
	Green self employed earnings	60,000	120,000	180,000	240,000
	NPV (6%)	458,988.18	831,946.17	1,110,642.08	1,318,899.87
	NPV (9%)	420,852.88	720,383.73	915,058.22	1,041,583.29
	NPV (12%)	387,198.32	629,553.08	767,071.69	845,103.44
	Simple payback periods (year)	0.33	0.16	0.10	0.08
	IRR (%)	319%	320%	320%	320%
Case 6	Environmental benefit	15,532	31,063	46,595	62,127
	Green self employed earnings	39,600	79,200	118,800	158,400
	NPV (6%)	26,870.17	79,110.88	118,148.19	147,319.13
	NPV (9%)	22,088.67	64,044.35	913,12.66	109,035.19
	NPV (12%)	17,899.16	51,846.11	71,108.52	82,038.53
	Simple payback periods (year)	3.61	1.15	0.68	0.49
	IRR (%)	32	42	44	44

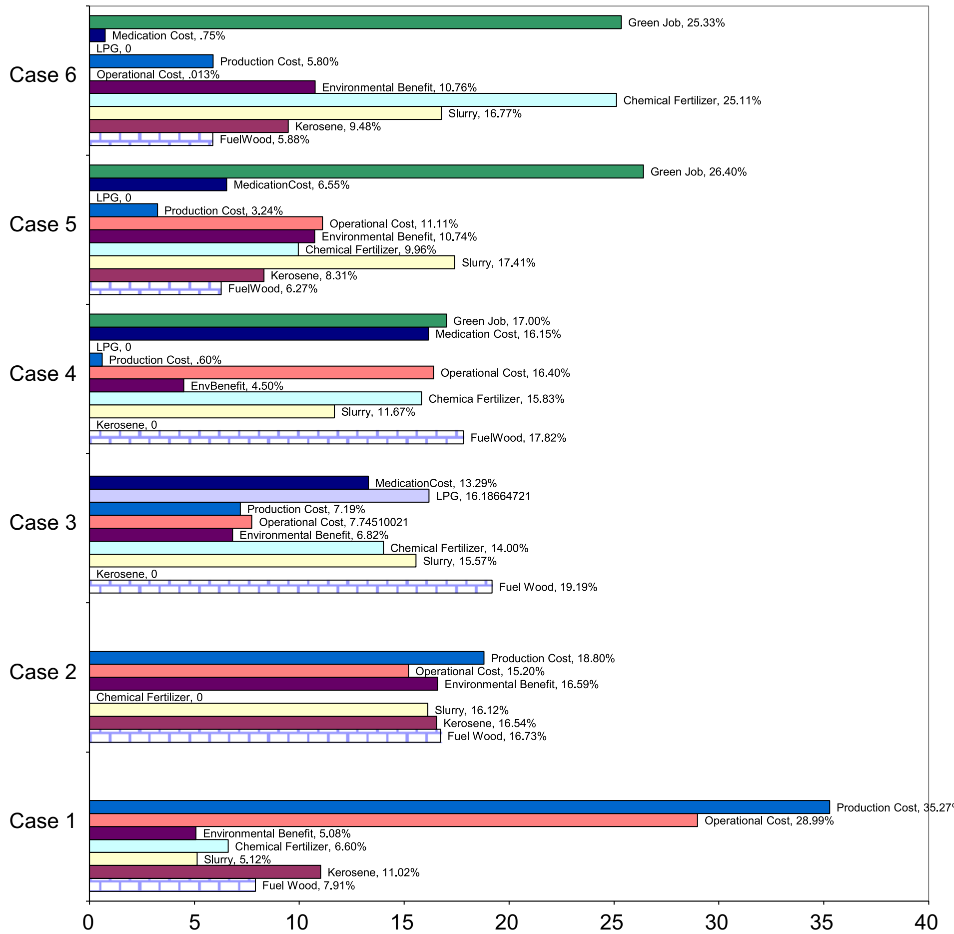

Fig. 4. Relative importance in sensitivity analysis using MLP model.

green jobs creation, cost of fuel wood, kerosene, LPG, associated production and operational costs, environmental benefit, chemical fertilizer and slurry usages. The sensitivity chart (Fig. 4) shows that the results are mostly sensitive to 'green job' in three cases (case-4, case-5 and case-6) followed by medical cost, income from slurry, and cost reduced from using chemical fertilizer. The average sensitivity factors of green job are highest for all these three cases, where NPV is positive for all time segments, which are 17.00%, 26.40%, and 25.33%, respectively. Unlike other cases, case-1, case-2 and case-3 have no green income and they are not economically feasible (case-1 and case-2 are not economically feasible for considering twenty years lifetime and case-3 is not economically feasible up to five years of lifetime). In a nutshell, green jobs play a major role in determining uncertainties associate with substitution of conventional cooking systems by biogas technology. In other words, green job plays more sensitive role than the other variables for determining success of a biogas plant.

Therefore, answer to be drawn from case studies is that some households with positive economic net benefit are not only using biogas for domestic energy needs for cooking but also use their saved time for small-scale business and generate income vis-à-vis employment. In other words, unlike other households (case-5 and case-6) with positive net economic benefit, some households (case-1 and case-2) with negative economic net benefit are not using biogas energy for any small business purpose. So, biogas struggle to compete with subsidized fossil fuel like kerosene or solid biomass (fuel wood) as long as household could not invest their saved time for income generating activities.

Therefore, it is evident from our analysis that households who are using their saved time to run a small business have a shorter length of payback periods, larger net present value and high internal rate of return than those households who are using biogas only for cooking purpose. One of the main reasons for the higher IRR and shorter break-even periods of the three cases (case-3, case-4 and case-6) is due to green employment: green energy creates green employment.

There are two types of green employment could be generated by biogas plants: organizational employment and household-based employment. There are a large number of governments and non-government organizations working to disseminate biogas technology to the remote part of the country, they appointed and trained a large number of organizational workforces [38]. This research particularly focused on self-employment generated by installing biogas for reducing user′s workload. Before biogas installation, women and children in the rural households usually spend most of their time on collecting firewood and cooking. Women are the ones who spend most of their time doing household activities such as livestock caring, fetching water, firewood collection, dung preparation for cooking, fodder collection for livestock, cooking food, etc. Biogas reduces women workload on an average 3 h a day by reducing firewood collection, cooking and washing of blackened cooking pots time. If this saved time were used for productive works such as poultry firming, fishing, gardening, education and other social activities, biogas could become an attractive economic means to create employment. Children could study and play more hours. This consequently will not only

increase income of the household members but increase children wellbeing.

Other than green alternative income due to effective workload reduction of women for cooking and collecting fire wood, economic feasibility varies considering different key parameters: fixed and variable cost of biogas plant, conventional energy savings in the form of wood, LPG, kerosene, and its associated cost of CO_2 in the environment and medical treatment due to accident in the last year, reduced use of chemical fertilizers due to production and use of slurry. Slurry is an important byproduct of biogas plant which reduces the use of chemical fertilizer uses. Waste slurry from biogas plans is excellent organic manure, which could increase agricultural production as well as nutritional status of the household.

By reducing indoor smoke and consequent ocular and respiratory infections, biogas digesters contribute to improved health and to proportional reductions in medical expenditure. Unlike wood, biogas is a clean, smokeless fuel, whereas the smoke from wood fires can lead to asthma, lung cancer and bronchitis. Switching to biogas stoves means cleaner, healthier homes, particularly benefiting women and children.

7. Conclusion

Main idea of this paper is to investigate the economic viability of biogas plants in rural Bangladesh by comparing 'ex ante' (without project) and 'ex post' (with project) situations. This paper defines economic viability as a systematic, sustainable and coherent approach that quantifies altogether technical (i.e. type of fuel used and corresponding time spent for cooking), financial (i.e. household′s income and expenses for fuel and fertilizer), social (i.e. time for wood collection, burning risk) and environmental (i.e. quantity of firewood used for cooking and corresponding carbon emission) cost-benefit of a biogas digester [11]. The objective of this paper is to evaluate and determine economic relevance and sustainability of biogas digesters in rural Bangladesh, where majority of the people are still using traditional fuel for cooking.

Until now biogas plants are not economically feasible for all cases even after considering environmental benefit for savings conventional sources of energy, on average 15 kg firewood per day are saved for each biogas-plant. Since biogas is mainly competing with solid biomass in rural Bangladesh which can be collected albeit free from local forest areas and road side trees, financial investment for biogas in some cases fail to breakeven over 20 years for artificially lower kerosene price and almost free fuel wood. The sensitivity analysis shows that economic viability depends positively on 'green job' creation, medical cost for burning, income from slurry, and cost reduced from using chemical fertilizer. So, biogas struggle to compete with subsidized fossil fuel like kerosene or solid biomass (fuel wood) as long as household could not invest their saved time for income generating activities.

Biogas reduces women workload on an average 3 h a day by reducing firewood collection, cooking and washing of blackened cooking pots time. If this saved time were used for productive works such as poultry firming, fishing, gardening, education and other income generating activities, biogas could become an attractive economic means to create employment. Such findings can be substantial for policy recommendation in favor of micro-credit with proper micro-insurance (e.g. cattle insurance) for biogas users to create green employment.

Apart from the reduction in women workload for collecting fuel wood, household biogas produce bio-slurry, main effluent of biogas plant and pure organic fertilizer that could be used as a suitable substitute for chemical fertilizers. Although bio-slurry is regarded as a great source of sustainable financial benefit for the biogas users in many countries [39,40], the sensitivity analysis of this paper showed financial contribution of 'bio-slurry' is not as important as other variables.

The reason is that most of the biogas plant owners are very much ignorant about proper management of bio-slurry, however, they are really concerned about long-term negative implications of applying chemical fertilizers. Many still believe that they cannot avoid this, because of a lack of alternatives and the risk of food shortages. Therefore, ignorance of using bio-slurry and increased use of chemical fertilizers has led to the contamination of water bodies and the spread of diseases, which have adversely affected aquatic life, livestock and people′s health and cause groundwater pollution in Bangladesh [41].

However, chemical fertilizers are subsidized directly and indirectly in the form of subsidy on natural gas for producing chemical fertilizers. The subsidy on chemical fertilizers encourages farmers to use more than optimal doses of fertilizers in Bangladesh [42], therefore decreases soil quality and creates environmental hazards. A proper soil fertility management is crucial for Bangladesh, where policy could be initiated to substitute conventional agricultural by ecological agriculture system and 'bio-slurry' could be an economically viable alternative if market distortions created by subsidies are corrected. The national government and NGOs could play a vital role in resolving both fuel and fertilizer crisis in rural Bangladesh by encouraging bio-gas plants. A gradual shift in attitudes and policy toward replacing chemical fertilizer subsidy program with a biogas price support program is essential; the main objective is to encourage farmers to switch from traditional agriculture to sustainable farming. Programme on proper use of slurry is indispensable for all the biogas construction companies to attract the new customer in rural Bangladesh. If bio-slurry can be properly managed by farmers, they will be definitely benefited and interested towards the biogas plant construction.

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Appendix A

Plant Information	Family size	Panel size	Monthly amount of installment	Amount of first payment	Number of cattle	Investment to purchase new cattle	Time saved for cooking and firewood collection	Green earning via self-employment	Number of operator	Operators salary	Plant feeding	Slurry
Case 1	8	2.4 m^3	Tk. 0	Tk. 23,000	3	Tk. 0	4 h/day	Tk. 0 /Year	1	Tk. 36,000 per year	35 kg/day	25 kg/day
Case 2	8	2.4 m^3	Tk. 1096	Tk. 5200	3	Tk. 0	2 h 30 min/day	Tk. 0 /Year	1	Tk. 40000 per year	30 kg/day	20 kg/day
Case 3	2	2.4 m^3	Tk. 835	Tk. 4000	2	Tk. 140,000	0 h/day	Tk. 0 /Year	1	Tk. 30,000 per year	65 kg/day	55 kg/day
Case 4	8	2.4 m^3	Tk. 819	Tk. 9841	3	Tk. 0	2 h/day	Tk. 14,400 /Year	1	Tk. 12,000 per year	65 kg/day	50 kg/day
Case 5	5	2.0 m^3	Tk. 654	Tk. 9246	8	Tk. 0	3 h/day	Tk. 12,000 /Year	0	Tk. 0 per year	60 kg/day	50 kg/day
Case 6	6	2.4 m^3	Tk. 1200	Tk. 4000	4	Tk. 0	5 h/day	Tk. 7920 /Year	1	Tk. 35,000 per year	50 kg/day	40 kg/day

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